U.S. Department of Energy
Office of Science

Occasional Paper: Biotechnology for Energy Security

Summary

The biotechnology revolution has potential benefits that extend well beyond the promise of increased human health and longevity. The Office of Science is now seeking to exploit that revolution to use plants, microbes, and microbial communities to produce energy, remove carbon dioxide from the atmosphere, and clean up hazardous waste.

The 21st Century is already being called the "biological century"—an era when advances in biology, spurred by achievements in genomic research, including the sequencing of the human genome, will bring revolutionary and unconventional solutions to some of our most pressing and expensive challenges in health, energy, the environment, and national security.

This new era of biology is one in which we will understand the workings of entire biological systems and not just bits and pieces of those systems. We will understand how living organisms interact with and respond to their environments. We will use that information to make biology work for us to produce clean energy, remove excess carbon dioxide from the atmosphere, help clean up the environment, or better detect and defeat bioterrorism.

While scientists have long tried to understand the workings of individual genes or small groups of genes, this new era of biology will focus on entire networks of genes and even entire biological systems—small, single-celled organisms at first, and later more complex creatures including humans. This dramatic advance is possible, in large part, because of the scientific and technical successes of the Human Genome Project. Begun by the Department of Energy's Office of Science, with its broad capabilities in engineering, computation, and biology, this project to sequence and understand the functions of human genomic DNA has revolutionized biology and taught us the value of high throughput, hypothesis-generating research.

The success of the Human Genome Project has led to similar projects and successes as the genomes of other organisms, from microbes to plants to worms to flies to mice, have been sequenced. The information and technology now available to all scientists as a result of this genomic research not only gives us new perspectives on the inner workings of biological systems, but also provides new opportunities to use this knowledge to solve national problems.

In recent years, DOE has made contributions to our Nation's biological research, an investment that made pivotal contributions to many national successes in the biological and medical sciences, e.g., the human genome project, medical imaging technology, medical isotopes for diagnostic imaging, chemical-biological sensors, and the National Institute of Health's new Protein Structure Initiative. While these basic research programs, new technologies, and resources for future research are, today, all "owned" by other agencies, they would not even exist were it not for investments in high risk, high payoff Office of Science research.

Genomes to Life is another such program. At the forefront of the biological revolution, Genomes to Life is a novel program at the interface of the biological, physical, and computational sciences. It will take advantage of solutions that nature has already devised to solve problems in energy production, environmental cleanup, carbon cycling, and even biological defense to help us use biology to design our own solutions to these national challenges.

Through Genomes to Life, we see the possibility of biotechnology solutions that can give us abundant sources of clean energy while controlling greenhouse gases like carbon dioxide, a key factor in global climate change. Beginning with our DNA sequencing successes and our ability to quickly, cheaply, and accurately determine the DNA sequence of microbes, Genomes to Life offers the promise of unconventional, biology-based solutions for energy security:

- Clean Energy—Within 10 years, advances in systems biology, computation, and technology will contribute to increased biology-based energy sources. By 2050 they will contribute to energy security through a major new bioenergy industry.
- Reduced Carbon Dioxide in the Atmosphere—Within 10 years, advances in systems biology, computation, and technology will help us understand earth's carbon cycle and design ways to enhance carbon capture. By 2040 they will contribute to stabilization of atmospheric carbon dioxide to counter global warming.

Over billions of years of evolution, nature has created a remarkable array of multi protein molecular machines with exquisitely precise and efficient functions and controls, including mechanical motion, molecular detection, chemical synthesis, and light emission and detection. Genomes to Life is a basic research program at the interface of the biological, physical, and computational sciences whose goal is to understand these molecular machines and their controls so well that we can use and even redesign them to address DOE and national needs. The possibilities are powerful and diverse:

- Plants that take up and retain more carbon from the atmosphere.
- Plants that grow faster or in places they wouldn't normally grow, are easier to harvest, or contain material more easily converted to clean energy.
- Microbes that convert sunlight or biomass to energy products without carbon dioxide as a byproduct.
- Microbes or communities of microbes able to increase the amount of carbon dioxide that soils and oceans can "permanently" remove from the atmosphere.
- Human-made molecular machines based on biological design principles that can be used to do all of these things more efficiently and more productively than their natural biological counterparts.

Genomes to Life is a program whose time has come. Building on the success of genomics research, on the Office of Science's capabilities in the physical and computational sciences, and on the remarkable diversity of Nature's own evolutionary designs, Genomes to Life will use a systems-level understanding of complex biological systems to develop biotechnology solutions for energy security.

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